California's Quakes Forecasted

The first official earthquake forecast for California emphasizes the broad extent of the hazard and the uncertainties involved in predicting the next quakes

FOR THE FIRST TIME, researchers have reached a consensus on the threat of large earthquakes to California. Things look no worse for Los Angeles than before. It still has about a 60% chance of being shaken by a large earthquake sometime during the next 30 years. But other heavily populated areas of California, such as San Bernardino and the East Bay area of San Francisco, are now getting their fair share of attention. The new consensus also points up the considerable uncertainties involved in earthquake forecasting.

A striking example of that uncertainty presented itself last fall when the group of a dozen experts, the U.S. Geological Survey's Working Group on California Earthquake Probabilities, concluded at its 23 November meeting that the available data could not justify one of its preliminary earthquake probabilities. The next day the discarded forecast's earthquake struck.

The uncertainties in earthquake forecasting are inherent in the approach adopted by the group. This forecasting approach initially assumes that breaks along faults such as the San Andreas occur a segment at a time. The method also assumes that the amount of stress required to break each segment is fixed. If these two assumptions hold, the result is a string of so-called characteristic earthquakes, each more or less identical to the next.

If a third assumption is fulfilled, that the rate at which stress accumulates is constant, then the characteristic earthquakes strike with the regularity of the ticking of a clock, or something close to it. A short section of the San Andreas in central California near Parkfield seems to have produced at least five characteristic earthquakes in a row, with more or less regular intervals of about 22 years (*Science*, 8 January, p. 145). There is other evidence supporting this time-predictable model, which the group applied to 17 fault segments, but, as the group's report makes clear, some faults are not always so well behaved.

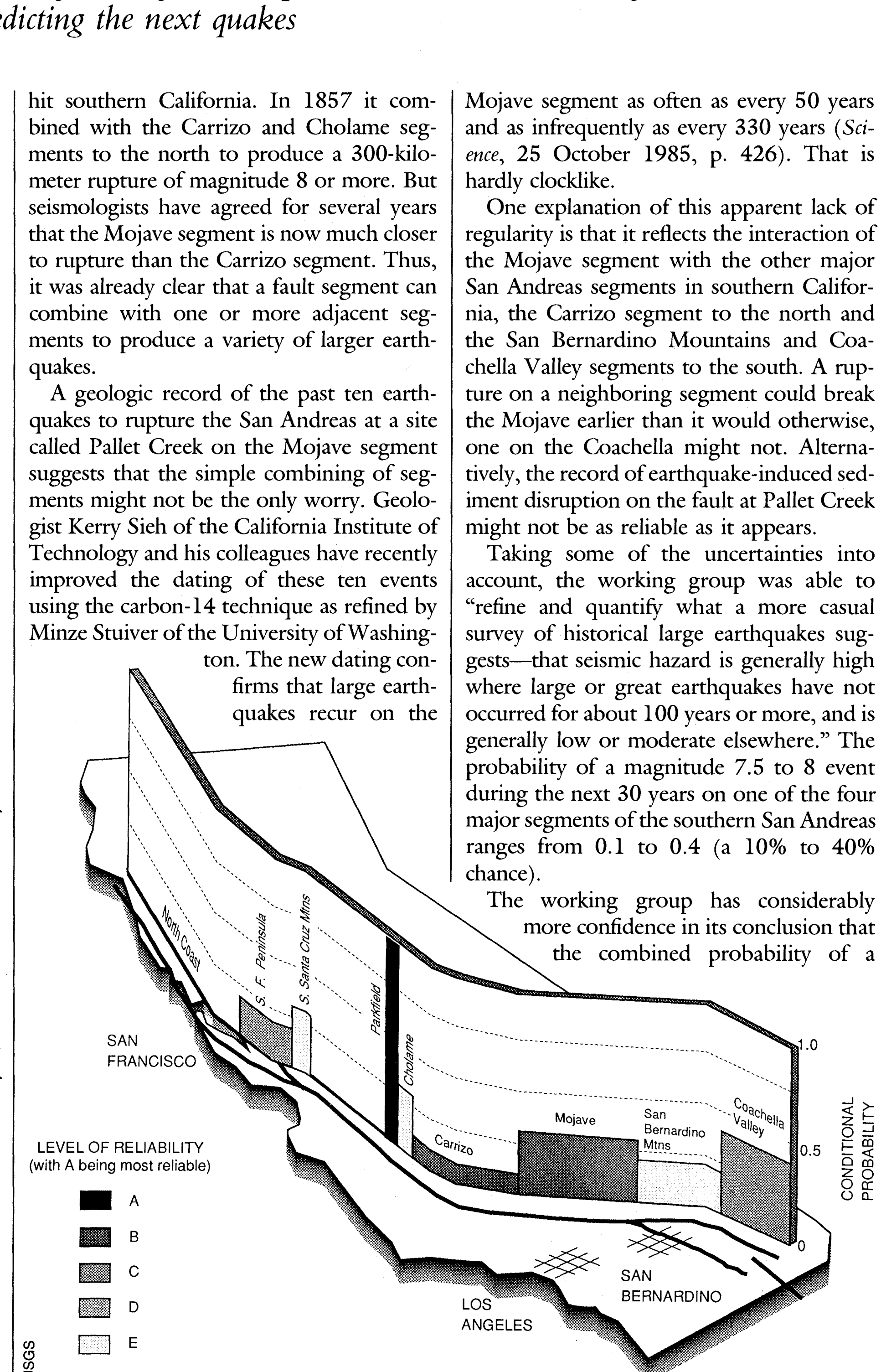
Disconcertingly, the most ill-behaved fault segment has the longest geologic record of the 17 considered. The Mojave segment, which is closest to Los Angeles, helped generate the most recent "big one" to hit southern California. In 1857 it combined with the Carrizo and Cholame segments to the north to produce a 300-kilometer rupture of magnitude 8 or more. But seismologists have agreed for several years that the Mojave segment is now much closer to rupture than the Carrizo segment. Thus, it was already clear that a fault segment can combine with one or more adjacent segments to produce a variety of larger earthquakes.

A geologic record of the past ten earthquakes to rupture the San Andreas at a site called Pallet Creek on the Mojave segment suggests that the simple combining of segments might not be the only worry. Geologist Kerry Sieh of the California Institute of Technology and his colleagues have recently improved the dating of these ten events using the carbon-14 technique as refined by Minze Stuiver of the University of Washington. The new dating confirms that large earthquakes recur on the Mojave segment as often as every 50 years and as infrequently as every 330 years (*Science*, 25 October 1985, p. 426). That is hardly clocklike.

One explanation of this apparent lack of regularity is that it reflects the interaction of the Mojave segment with the other major San Andreas segments in southern California, the Carrizo segment to the north and the San Bernardino Mountains and Coachella Valley segments to the south. A rupture on a neighboring segment could break the Mojave earlier than it would otherwise, one on the Coachella might not. Alternatively, the record of earthquake-induced sediment disruption on the fault at Pallet Creek might not be as reliable as it appears.

Taking some of the uncertainties into account, the working group was able to "refine and quantify what a more casual survey of historical large earthquakes suggests—that seismic hazard is generally high where large or great earthquakes have not occurred for about 100 years or more, and is generally low or moderate elsewhere." The probability of a magnitude 7.5 to 8 event during the next 30 years on one of the four major segments of the southern San Andreas ranges from 0.1 to 0.4 (a 10% to 40% chance).

The working group has considerably more confidence in its conclusion that the combined probability of a



The chances for major earthquakes in the next 30 years. *Along the San Andreas fault, the highest probabilities for a large earthquake between 1988 and 2018 are in southern California near Los Angeles and San Bernardino. A moderate earthquake at Parkfield, which is nearly empty cow country, is expected at any time.*

large earthquake somewhere on the southern San Andreas in the next 30 years is a hefty 0.7. An individual segment might have its irregularities, the reasoning goes, but the two plates on either side of the fault are inexorably moving past each other. Something is likely to give somewhere soon.

When it does, the triggering of one or more segments by the initial failure is a real possibility. With little to go on, the working group judged that two possibilities are equally probable—the central San Bernardino Mountains segment could break independently of its neighbors or it could trigger failure of one of them. If triggering occurred, the two segments would produce a magnitude 7.8 shock. That has a 30-year probability of 0.6.

If this bodes ill for nearby Los Angeles, San Bernardino and its environs look to be worse off. Not only must this city contend with the San Andreas on its northern edge, but it is also cut by the San Jacinto. The combined probability for the northern three segments on the San Jacinto is 0.5 for a magnitude 6.5 to 7.0 earthquake during the next 30 years. The magnitude 5.9 Whittier earthquake within the Los Angeles area last year caused $350 million in losses.

The other area of particular concern is the East Bay of San Francisco, where the Hayward fault cuts across the cities of Hayward, Fremont, Oakland, and Berkeley, not to mention slicing through the stadium at the University of California and the BART subway tunnel. The 0.2 30-year probability assigned to a magnitude 7 shock somewhere on the Hayward is not that precise, but the combined probability for the Hayward and San Francisco Peninsula faults is 0.5.

A scenario developed recently by the California Department of Conservation tells emergency response personnel that they can assume for planning purposes that a magnitude 7.5 shock, the largest credible rupture on the Hayward, would kill 1,500 to 4,500 persons and injure more than 50,000. An inescapable social upheaval would engulf the more than 5 million residents of the area as the rupture and its shaking severed the "lifelines" of power, fuel, transportation, water, sewage, and communication that stitch together the social fabric.

It gets worse for California. The working group freely admits that no one has identified all the faults that can cause damaging earthquakes. The surprise Whittier earthquake is a case in point. And, due to a dearth of information, the group chose not to evaluate the potential of numerous less dangerous faults. "Collectively, however, these faults may present a hazard comparable to those studied in this report," it is cautioned.

■ RICHARD A. KERR

The Prediction Record So Far

Time will tell just how good the state of the art of earthquake forecasting is in 1988, but seismologists already have a track record. It is mixed.

In the realm of long-term forecasts, Allan Lindh of the U.S. Geological Survey (USGS) in Menlo Park has compiled preliminary 30-year probabilities for large earthquakes on about a dozen segments of the San Andreas system. After 5 years, the forecast is intact—none of the most probable events is overdue and none of the least probable events has occurred. Robert Wesson and Craig Nicholson of the USGS in Reston, Virginia, have already had one success—the Superstition Hills earthquake of last year—from their list of 16 earthquakes larger than magnitude 5.7 that have a high probability of striking California during the 10 years beginning in November 1986. They also missed one event that size, but three that were a bit too small (about magnitude 5) struck designated areas.

On a larger geographic scale, Stuart Nishenko of the USGS in Denver reports that since 1968, 13 large or great earthquakes have struck fault segments around the Pacific region that had been identified as overdue for failure. Only one earthquake, the 1986 Andreanof Islands quake in Alaska, struck where recent activity seemed to imply minimal immediate hazard, Nishenko says.

When it comes to predictions, that is, statements that include a specific time, place, and magnitude, the record is skimpier. In 1985 Max Wyss of the University of Colorado and Robert Burford of the USGS in Menlo Park predicted that three moderate earthquakes of magnitude 4 to 5 would break the San Andreas near San Juan Bautista. They largely based their predictions on periods of decreased seismic activity that seemed to precede some mainshocks. One earthquake struck as predicted at Stone Canyon and two did not occur, but another quake ruptured an adjacent segment of the fault that they had included in their study.

Researchers have questioned the utility of a method that yields one success, two false alarms, and a miss. More quantitatively, Paul Reasenberg of the USGS in Menlo Park and Mark Matthews of Stanford University verified the periods of quiescence found by Wyss and Burford, but found only the one at Stone Canyon to be statistically significant. Examining seismic activity preceding 37 earthquakes in California and Japan, they found no evidence "for a systematic, widespread, or reliable pattern of quiescence prior to the mainshocks." The growing number of reported successes based on quiescence can be attributed to the preferential reporting of successes over failures, they say.

Seismic quiescence recently led to another prediction, with an equally equivocal outcome. In 1985 Carl Kisslinger of the University of Colorado predicted a magnitude 7 to 7.5 event near Adak Island in the Aleutians. A large earthquake did subsequently rupture the specified fault segment in 1986, but that was about all that was strictly consistent with the prediction. The actual event was magnitude 7.7, not 7 to 7.5, it struck 6 months after the predicted time window closed, and its rupture began 150 kilometers from where predicted. The National Earthquake Prediction Council (NEPEC) concluded that "although your [Kisslinger's] prediction was not borne out, the seismic quiescence pattern you reported might well be related to the stress accumulation process associated with the 1986 earthquake."

Less formal efforts have been made as well. Three times during the past 3 years recent seismic activity prompted the California Office of Emergency Services to issue "advisories," not predictions, to local governments. Each advisory pointed out that, on the basis of past experience, such activity tends to increase the probability of a larger earthquake in the near future. In these three cases, however, nothing happened after the advisories were issued.

Although most forecasts, predictions, and advisories have been based on large-scale patterns of seismicity, the great hope for prediction, especially short-term prediction, is direct measurement of fault behavior. The focus for short-term prediction is a short segment of the San Andreas fault near Parkfield in central California (*Science*, 8 January, p. 145). Dense networks of instruments are now monitoring the fault there in anticipation of a moderate magnitude 6 earthquake predicted for January 1988 plus or minus 5.2 years (95% confidence interval). Because of this attention and its uniqueness as the one prediction endorsed by NEPEC, the outcome of the Parkfield Earthquake Prediction Experiment will be pivotal. ■ R.A.K.